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Recent geological and geodetic studies have suggested that the region surrounding Vandenberg AFB is undergoing active crustal deformation, with important implications for both the geodetic stability and the seismogenic potential of the Western Test Range (WTR) [Feigl et al., 1990]. Part of the evidence for significant deformation was obtained from GPS measurements which we carried out in cooperation with other university and government scientists beginning in late 1986. These measurements were made annually through 1991 over a broad region of central and southern California but were of insufficient spatial and temporal density to answer important questions about the seismogenic potential of Vandenberg.

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Final Technical Report

covering the period

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Submitted to

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SUMMARY

Recent geological and geodetic studies have suggested that the region surrounding Vandenberg AFB is undergoing active crustal deformation, with important implications for both the geodetic stability and the seismogenic potential of the Western Test Range (WTR) [*Feigl et al.*, 1990]. Part of the evidence for significant deformation was obtained from GPS measurements which we carried out in cooperation with other university and government scientists beginning in late 1986. These measurements were made annually through 1991 over a broad region of central and southern California but were of insufficient spatial and temporal density to answer many important questions about the seismogenic potential of Vandenberg.

In 1989 we received funding under this grant (with matching funds from MIT) to purchase GPS receivers and to begin a series of measurements designed to determine the magnitude and spatial distribution of deformation in a region encompassing the major faults and folds within 50 km of Vandenberg. We acquired four receivers in January 1990 and carried out three two-week experiments between February 1990 and March 1992. Two additional receivers were purchased in May 1992 and installed in continuously operating GPS stations at Vandenberg and the China Lake Naval Air Weapons Station. They have become part of the Permanent GPS Geodetic Array (PGGA) in California, providing the ability to monitor not only interseismic deformation but any transient motion which might occur prior to, during, or after an earthquake. The Vandenberg station provided a far-field anchor for the first measurements of a major earthquake by a continuously operating GPS array [*Bock et al.*, 1992].

Most of the observations and data analysis for the Vandenberg network have been funded by a complementary research grant (AFOSR 90-0339). We postpone to the final report for this grant, due two months hence, a detailed description of our scientific results. We do include with this report, however, an explanation of the equipment purchased and a list of publications that have resulted from its use.

GPS FIELD RECEIVERS AND MEASUREMENTS PERFORMED 1990–1992

In our original proposal to AFOSR, submitted in January 1989, we proposed to acquire three second- or third-generation GPS receivers at an anticipated cost of $65K–$95K each. By the time we received funding, the price of receivers had dropped to $35K, in part because of a large-purchase agreement negotiated with Trimble Navigation by the University Navstar Consortium (UNAVCO). Hence, we requested and received permission from AFOSR to acquire four receivers for field use in late 1989.

In February 1990 we carried out the first GPS measurements of a densely spaced geodetic network near Vandenberg. This experiment was designed to test the new receivers, to remeasure four sites first observed in 1987 and 1989, and to add three additional sites to the network. In September 1990 we reoccupied all eight of the previously established sites in the network and added one additional site in a region where it had been difficult to find a monument in stable terrain. Analysis of these two experiments, in conjunction with our earlier observations, formed the basis of an improved assessment of deformation near Vandenberg in the Ph. D. thesis of MIT graduate student Kurt Feigl [*Feigl*, 1991]. In March 1992 we remeasured the relative positions of eight of the Vandenberg-network stations occupied in the first two experiments and also established nine new stations to further densify the network. The data from all three experiments have been incorporated into an analysis of deformation for central and southern California being completed in the spring of 1993 [*Feigl et al.*, 1993].

When not deployed at Vandenberg, our four GPS field receivers have been used for crustal deformation surveys in other parts of California, most notably in the Los Angeles [*Hudnut*, 1990] and Ventura [*Donnellan et al.*, 1993a,b] basins, Salton Trough [*Reilinger and Larsen*, 1992], and Parkfield. They were also used for post-seismic measurements following the 1992 Joshua Tree, Landers, and Big Bear earthquakes [*Hudnut et al.*, 1992] Finally, as part of our maintenance agreement with UNAVCO, the receivers have been loaned for 3- to 6-months of each year for NSF-sponsored projects in other parts of the world.

CONTINUOUSLY OPERATING GPS STATIONS AT VANDENBERG AND CHINA LAKE

A significant expansion in the scope of our original proposal was made possible by discussions in late 1989 between MIT, Scripps Institution of Oceanography, and the Jet Propulsion Laboratory to establish a continuously operating, Permanent GPS Geodetic Array (PGGA) in southern California. Such an array provides a more accurate and cost-effective means for monitoring crustal deformation. It also presents the possibility of detecting transient motions that would be missed by temporally sparse field campaigns.

Between 1989 and 1991 we carried out an extensive series of discussions with officials at Vandenberg concerning the siting and installation of a PGGA station on south base. The requirements for the site are stringent and complex: 1) geological stability, 2) available power and communications lines, 3) freedom from obstructions and radio-frequency interference, 4) acceptable environmental impact. In October 1989 we met with SAC and WTR officials responsible for radio-frequency control, civil engineering, and environmental affairs, and with representatives from NASA and the DMA Geodetic Survey Group, our primary liaison for GPS work. At the same time we conducted a reconnaissance survey of four possible sites. This meeting and survey narrowed our choice to the vicinity of the existing NASA VLBI site, and in January 1990 we submitted a formal request through USAF channels for an upgrade of the facility to include the new GPS station. Our original choice of a site was found to be in an area known to have archaeological artifacts, so we shifted our interest to a new area several hundred meters away. In order to assess the geological stability of the new area, in September 1990 we supervised the drilling of five test holes from which we selected a site for the station. In mid-1991 we constructed there a high-stability geodetic monument of the type designed by Dr. Frank Wyatt of Scripps for other stations of the PGGA.

In early 1992, we requested and received approval to install a second Air Force PGGA station at the China Lake Naval Air Weapons Station. This region is one of the most seismically active in California, with a large number of small-to-moderate earthquakes stimulated by magma intrusion. In cooperation with Navy geologists and our colleagues at Scripps, we carried out site selection and monument installation for a station on Joshua Ridge in the Coso Range in late 1992 and early 1993.

We delayed the purchase of receivers for both the Vandenberg and China Lake stations until May, 1992, again in order to take advantage of improved technology and reduction in cost made possible by a multiple-receiver purchase negotiated with Ashtech, Inc., by Scripps.

An unexpected result from the Vandenberg PGGA station has been the contribution of its observations to geodetic determination of far-field displacements from the Landers (M_w 7.3) and Big Bear (M_w 6.2) earthquakes of 28 June 1992. These earthquakes occurred within 100 km of the PGGA sites at Pinyon Flat Observatory, operated by Scripps, and the NASA Goldstone Complex. These two sites, plus the PGGA sites at Scripps in San Diego and the Jet Propulsion Laboratory in Pasadena, were displaced by more than 15 mm by the earthquakes. The observed displacement at Vandenberg was 6 ± 3 mm, marginally different from the 3 mm displacement predicted by a variable-slip dislocation model computed from observed near-fault displacements. The lower observed far-field displacement may be evidence of the mantle, which has higher values of elastic moduli than the crust. Further analysis of the PGGA data before and after the earthquakes may allow a reduction in the uncertainties of our estimates of coseismic displacement, as well as detection of pre- or post-seismic motion [*Bock et al.*, 1992].

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